L4- Measurement units and standards Analog and Digital Measurements (EE 300/EE307)

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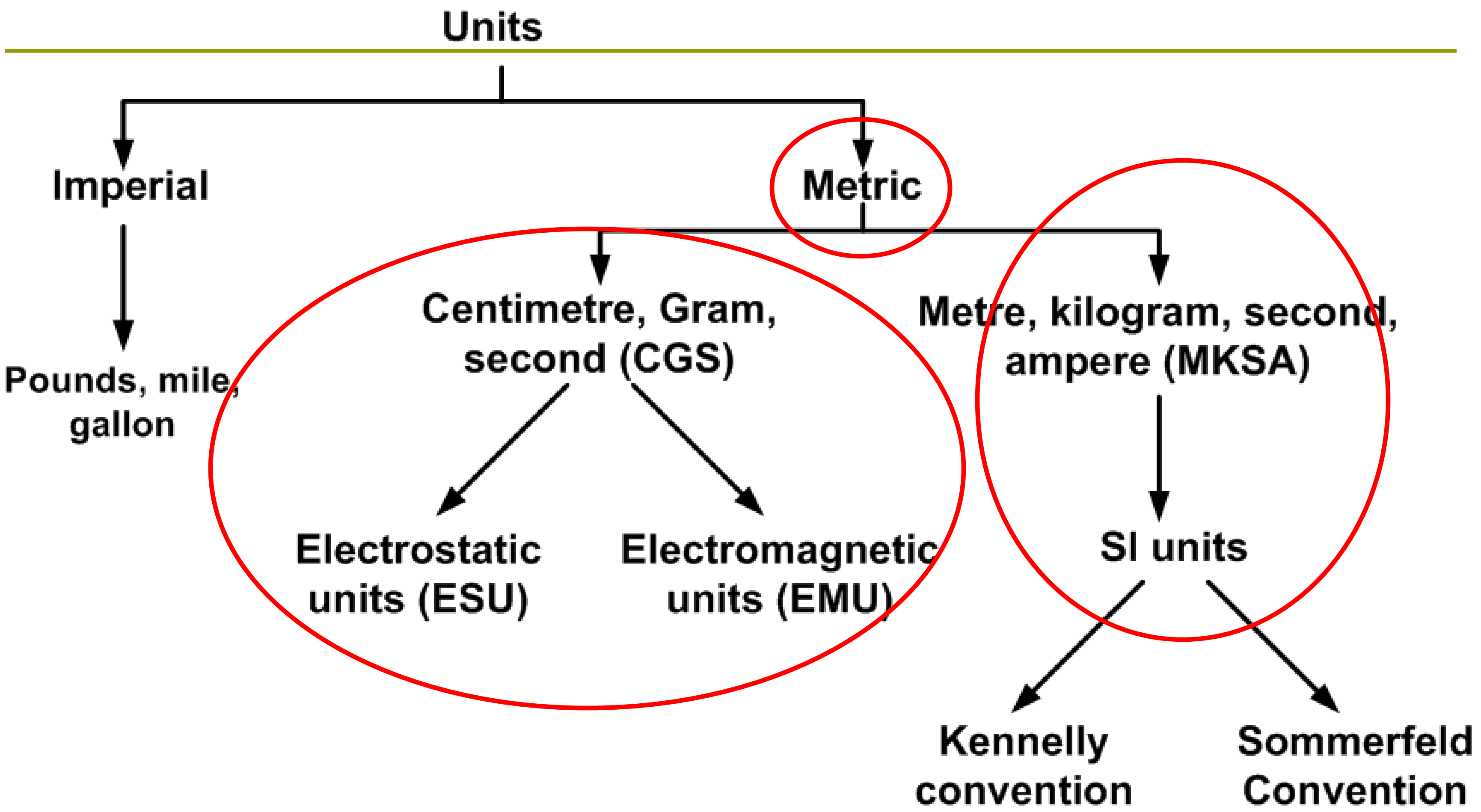
Units

- Units of measurement define the definite magnitude of physical quantity which adopt convention and law.
  - Eg. Unit for physical quantity **length** is **metre**

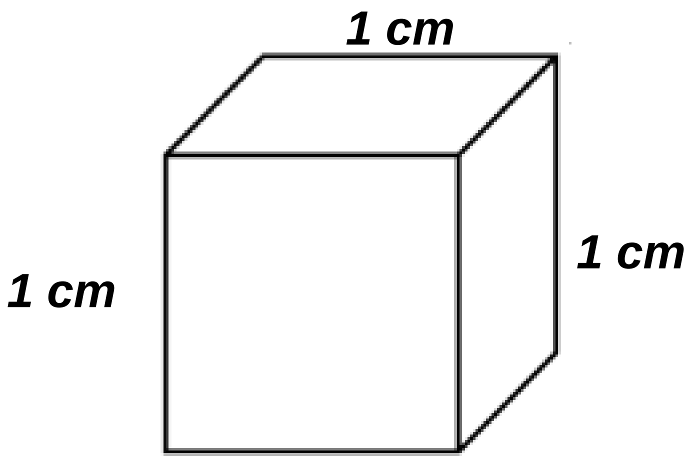
- The International System of units (SI unit) is a form of metric sys. & divided in 3 classes
  - base units
  - derived units
  - supplementary units

Units


Units
Imperial
Metric
Pounds, mile, gallon
Centimetre, Gram, second (CGS)
Metre, kilogram, second, ampere (MKSA)
Electrostatic units (ESU)
Electromagnetic units (EMU)
SI units
Kennelly convention
Sommerfeld Convention

Metric System

- *The Canadian Standard Kilogram. The kilogram is the only unit in the metric system defined by an actual object.*



A cube of water with sides each 1 cm has a mass of 1 gram

Units (SI)

Principles of the SI system

- SI stands for Systéme International d'Unités, i.e. the International System of Units. SI is the abbreviation used in all languages to indicate the system.

- The SI is constructed from seven base units, which are defined in physical terms.

- By combining these units in accordance with simple geometrical and physical laws, we can arrive at the derived units.

- In principle, the SI covers all application areas, although certain units outside SI are so useful that they are accepted for general use together with the SI (e.g degree, hour, day, minute)

Units– SI Prefix

10^n	Prefix	Sym	Short scale	Long scale	Decimal equivalent
10^{15}	peta	P	Quadrillion	Billiard (thousand billion)	1 000 000 000 000 000
10^{12}	tera	T	Trillion	Billion	1 000 000 000 000
10^{9}	giga	G	Billion	Milliard (thousand million)	1 000 000 000
10^{6}	mega	M	Million		1 000 000
10^{3}	kilo	k	Thousand		1 000
10^{2}	hecto	h	Hundred		100
10^{1}	deca	da	Ten		10
10^{-1}	Deci	d	tenth		0.1
10^{-2}	centi	c	hundredth		0.01
10^{-3}	milli	m	thousandth		0.001
10^{-6}	micro	µ	millionth		0.000 001
10^{-9}	nano	n	Billionth	Milliardth	0.000 000 001
10^{-12}	pico	p	Trillionth	Billionth	0.000 000 000 001
10^{-15}	temto	f	Quadrilliont	Billiardth	0.000 000 000 000 001

Units

SI units – base unit

- fundamental unit refers to quantity

NAME	SYMBOL	QUANTITY
Kilogram	kg	Mass
Second	s	Time
Meter	m	Length
Ampere	A	Electrical current
Kelvin	K	Temperature
Mole	mol	Amount of substance
Candela	cd	Luminous intensity
radian	rad	Plane Angle
steradian	sr	Solid angle

Units

SI units – derived unit

- derivation/further ext./combination . unit of base unit by means of the mathematical operations of multiplication and division.

Derived quantity	Derived unit	Symbol
Current density	Ampere per square metre	$A \cdot m^{-2}$
Moment of force	Newton metre	$N \cdot m^{3}$
Electric field strength	Volt per metre	$V \cdot m^{-1}$
Permeability	Henry per metre	$H \cdot m^{-1}$
Permittivity	Farad per metre	$F \cdot m^{-1}$
Specific heat capacity	Joule per kilogram	$J \cdot kg^{-1} \cdot K^{-1}$
Amount-of-substance concentration	Mol per cubic metre	$mol \cdot m^{-3}$
luminance	Candela per square metre	$cd \cdot m^{-2}$

Units

SI units – derived unit

- derivation/further ext./combination . unit of base unit

Derived quantity	SI D.U. name	Symbol	In SI units	In SI base units
Frequency	Hertz	Hz		s^{-1}
Force	Newton	N		$m \cdot kg \cdot s^{-2}$
Energy, work, quantity of heat	Joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
Power, radiant flux	Watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
Electric charge, quantity of elect.	Coulomb	C		$s \cdot A$
Electric potential difference, emf	Volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
Electric capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
Electric resistance	ohm		V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
Electric conductance	Siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
Magnetic flux	Weber	Wb	$V \cdot S$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
Magnetic induction, flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
Inductance	Henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$

Units

Derived quantity	SI derived unit name	Symbol	In SI units	In SI base units
Luminous flux	Lumen	lm	Cd ·sr	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	Lux	lx	Lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
Plane angle	Radian	rad		$m^1 \cdot m^{-1} = 1$
Solid angle	Steradian	sr		$m^2 \cdot m^{-2} = 1$
Moment of force	Newton metre	N·m		$m^2 \cdot kg \cdot s^{-2}$
Angular velocity	Radian per sec.	rad/s		$m^1 \cdot m^{-1} \cdot s^{-1} = s^{-1}$
Angular acceleration	Radian per second squared	rad/s^2		$m \cdot m^{-1} \cdot s^{-2} = s^{-2}$
Permittivity	Farad per metre	F/m		$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
Permeability	Henry per metre	H/m		$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
Energy density	Joule per m^3	J/m^3		$m^{-1} \cdot kg \cdot s^{-2}$
Electric field strength	Volt per metre	V/m		$m \cdot kg \cdot s^{-2}$
Electric charge density	Coulomb per cubic metre	C/m^3		$m^{-3} \cdot s \cdot A$
Electric flux density	Coulomb per m^2	C/m^2		$m^{-2} \cdot s \cdot A$

Dimension

- parameter or measurement used to describe some relevant characteristic of an object.
- dimensions is describing the size or spatial characteristic of an object: length, width, and height
- also for other physical parameters such as the mass and electric charge of an object

3-Dimension of gear system

Dimension

Dimension of Physical Quantities

- Uses symbol M (mass), L (length), T (time) –known as mech. unit, Q (e' charge), I - or A (current)

- A derived unit of physical quantity

- Example 1;
  - Dimension of physical quantity SPEED is L/T
  (or in units m/s, km/h, mph)

QUANTITY	UNIT	DIMENSION
SPEED	m/s	L/T

Dimension

- Dimension of a physical quantity is the total of all units attached to it.
  - For example, speed is given as distance *x* time; metres/second (m/s) MKS and centimetres/second (cm/s) in CGS system.
  - Dimension of measurement of speed ,

    [v] = [L]/[T]

Physical Quantity	Dimension
Length	$[M^0 L^1 T^0]$
Mass	$[M^1 L^0 T^0]$
Area	$[M^0 L^2 T^0]$
Speed, velocity	$[M^0 L^1 T^{-1}]$
Acceleration	$[M^0 L^1 T^{-2}]$

Dimension

Dimension of Physical Quantities

- Example 2;

Velocity = length/time

$$[v] = [L]/[T] = [LT^{-1}]$$

Acceleration = velocity/time

$$[a] \quad = [v]/[T] = [LT^{-1}]/[T^{1}] = [LT^{-2}]$$

Force = mass × acceleration

$$[F] = [M] \bullet [LT^{-2}] = [MLT^{-2}]$$

Dimension

Dimensional Consistency

Dimensions and units must be handled consistently in any algebraic calculation. Two quantities must have the same dimensions and units.

- Checking dimensions for the famous formula $E = mc^2$

$$(\text{energy}) = (\text{mass})\ (\text{speed})^2$$
$$(\text{force})\ (\text{length}) = (\text{mass})\ (\text{length/time})^2$$
$$(\text{mass})\ (\text{acceleration})\ (\text{length}) = (\text{mass})\ (\text{length})^2/(\text{time})^2$$
$$(\text{mass})\ (\text{length/time}^2)\ (\text{length}) = (\text{mass})\ (\text{length})^2/(\text{time})^2$$
$$(\text{mass})\ (\text{length})^2/(\text{time})^2 = (\text{mass})\ (\text{length})^2/(\text{time})^2$$

Dimensional

Consistency Dimension

- Ohm's Law

$$V = \frac{P}{I} = \frac{\frac{dE}{dt}}{[A]} = \frac{\frac{F \cdot ds}{dt}}{[A]} = \frac{\frac{m \cdot a \cdot ds}{dt}}{[A]}$$

$$= \frac{\frac{m \cdot \frac{d^2 s}{dt^2} \cdot ds}{dt}}{[A]} = \frac{\frac{[kg] \cdot \left[\frac{m}{s^2}\right] \cdot [m]}{[s]}}{[A]} \Rightarrow [V] = \left[\frac{kg \cdot m^2}{s^3 \cdot A}\right]$$

Practical Unit

- Unit representing physical quantities

No	Quantity	Practical Unit	Symbol	No of e.m. C.G.S. unit in one practical unit	Definition
1	Charge	Coulumb	Q	10^{-1}	$Q = I\,t$
2	Current	Ampere	I	10^{-1}	
3	Voltage	Volt	E	10^{8}	$E = I\,R$
4	Resistance	Ohm	R	10^{9}	
5	Inductance	Henry	L	10^{9}	$E = Ldl/dt$
6	Capacitance	Farad	C	10^{-9}	$Q = C\,E$
7	Power	Watt	P	1 Watt = 10^{7} energy/sec	
8	Energy	Joule	W	1 Joule = 10^{7} erg 1 kWh = 3.6×10^{3} erg	

SI units: base and additional

QUANTITY	UNIT	SYMBOL	DIMENSION	DEFINITION (STANDARDS)
1. Length	meter	m	L	Equal to 1,650,763.73 wavelengths in vacuum of the orange-red line of the krypton-86 spectra.
2. Mass	kilogram	kg	M	Cylinder of platinum-iridium alloy kept in France and a number of copies. (May be replaced by an atomic standard within the next ten years.)
3. Time	second	s	T	Time for 9,192,631,770 cycles of resonance vibration of the cesium-133 atom.
4. Temperature	kelvin	K	K	Absolute zero is defined as 0 kelvin. 0 degrees Celsius equals 273.16 kelvins.
5. Luminosity	candela	C	C	Intensity of a light source (frequency 5.40×10^{14} Hz) that gives a radiant intensity of 1/683 watts/steradian in a given direction.
6. Electric current	ampere	A	I	Current that produces a force of 2.10^{-7} newtons per meter between a pair of infinitely long parallel wires 1 meter apart in a vacuum.
7. Amount of substance	mole	mol	–	Number of elementary entities of a substance equal to the number of atoms in 0.012 kg of carbon 12.
*Angle	radian	rad	–	The angle subtended at the center of a circle by an arc that is of the same length as the radius.
*Solid angle	steradian	sr	–	The solid angle subtended at the center of a sphere by an area on its surface equal to the square of its radius.

SI units: base and additional

QUANTITY	UNIT	SYMBOL	DIMENSION	DEFINITION
Acceleration	meter/s/s	$m\ s^{-2}$	ML^{-2}	Rate of change of velocity of 1 meter per 1 second per one second.
Area	square meter	m^2	M^2	Multiplication of two orthogonal (right-angle) lengths in meters
Volume	cubic meter	m^3	M^3	Multiplication of three mutually orthogonal (right-angle) lengths in meters.
Force	newton	N	MLT^{-2}	The force required to accelerate a 1 kilogram mass 1 meter / second / second.
Charge	coulomb	C	IT	Quantity of electricity carried by a current of 1 ampere for 1 second.
Energy	joule	J	ML^2T^{-2}	Work done by a force of 1 newton moving through a distance of 1 meter in the direction of the force.
Power	watt	W	ML^2T^{-3}	Energy expenditure at a rate of 1 joule per 1 second.
Resistance	ohm	Ω	$ML^2T^{-3}I^{-2}$	Resistance that produces a 1 volt drop with a 1 ampere current.
Frequency	hertz	Hz	T^{-1}	Number of cycles in 1 second.
Pressure	pascal	Pa	$ML^{-1}T^{-2}$	Pressure due a a force of 1 newton applied over an area of 1 square meter.
Velocity	meter/s	$m\ s^{-1}$	LT^{-1}	Rate of movement in a direction of 1 meter in 1 second.
Potential (emf)	volt	V	$ML^2T^{-3}I^{-1}$	The potential when 1 joule of work is done in making 1 coulomb of electricity flow.

Standards

- The terms *unit* and *physical quantity* are both abstract concepts. In order to use a unit as a measure, there must be a realization of the unit available: a physical standard.

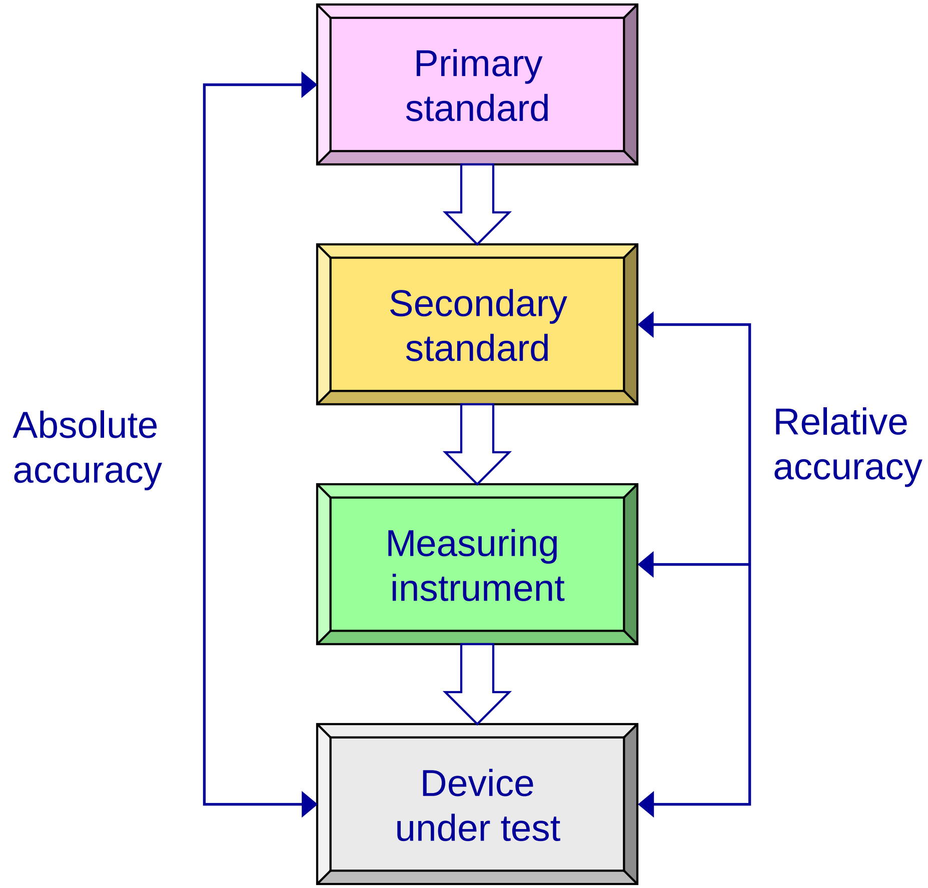
- A standard can be:
  - an artifact (prototype);
  - a natural phenomenon (atomic processes, etc.);
  - a standardized procedure of measurement using standardized measurement methods and equipment

Standards

- There are primary and secondary standards.
- Primary standards are preserved and improved in a national institute of standards and technology.
- Measurements are usually based on secondary or lower order (working) standards.
- These are calibrated to higher (primary or secondary) standards.
- An even lower order standard (reference) is present in every instrument that can perform an absolute measurement.
- Such instruments should also be calibrated regularly, since aging, drift, wear, etc., will cause the internal reference to become less accurate.
- Accuracy is defined here as an expression of the closeness of the value of the reference to the primary standard value.

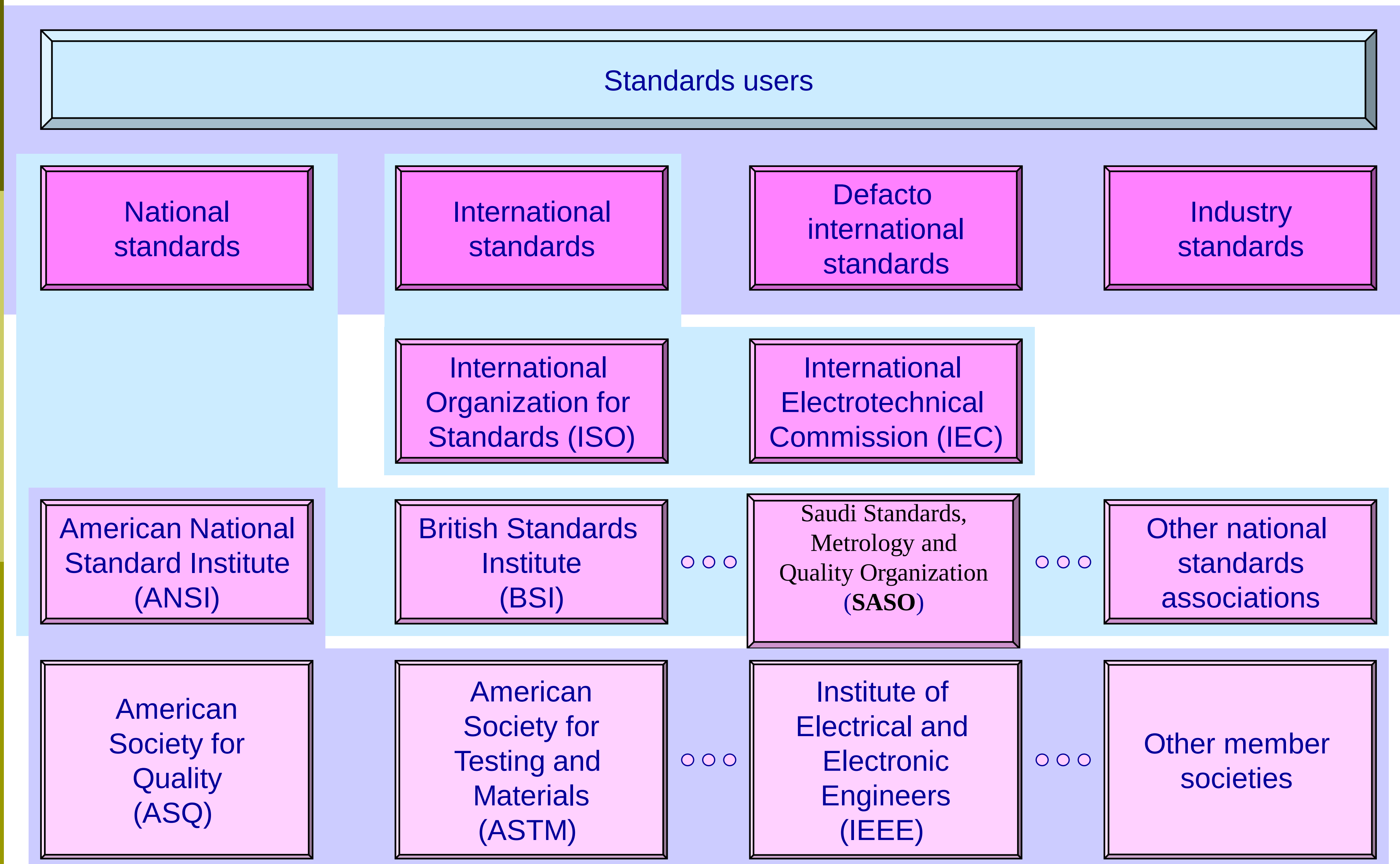
Standards

The hierarchy of standards



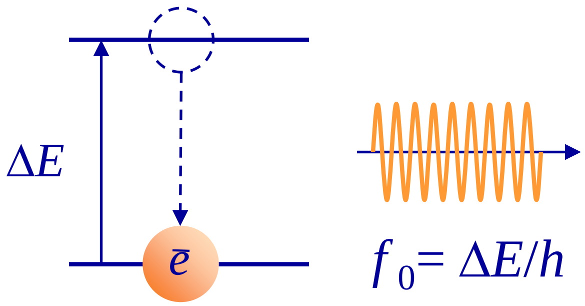
Standards

Measurement standards



Primary standards

Primary frequency standard



The atoms of Cesium-133 are selected with electrons jumping to a lower energy level and emitting photons at f_0= 9.19263177160 GHz. The unit of time, 1 s, is defined as the duration of exactly f_0 cycles. A crystal oscillator in the feedback loop of the exciter is used to adjust the frequency of the standard to that frequency at which most transactions occur. (The quality factor of so tuned standard $Q=2\times10^7$.)

Measurement uncertainty: $\pm1\times10^{-12}$ s ($\pm 10^{-6}$ ppm).